Average Spectral Energy Distributions of Blazars from Radio to γ–rays

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Abstract: The average Spectral Energy Distributions (SED) of different classes of blazars from the radio to the gamma–ray band are studied adopting a "complete–sample" approach. The SED are globally similar, despite systematic differences in specific frequency ranges, showing two broad peaks. However, i) the first and second peak occur in different frequency ranges for different objects, with a tendency for the most luminous sources to peak at lower frequencies, ii) the ratio between the two peak frequencies *seems to be constant*, iii) the luminosity ratio between the high and low frequency component increases with the bolometric luminosity.

1 The Blazar Family

The blazars family comprises various kind of sources showing a broad range of properties, thus raising the question as to up to which degree and in which form they are physically related. For instance: i) the properties of BL Lac objects selected in the radio/X–ray spectral bands are systematically different, the first difference to be recognized and perhaps still the most striking being the shape of the SED. ii) is there any difference between γ–ray detected blazars and the rest of the class ?

We would like to shed light on these kind of issues adopting an objective point of view. In the absence of "blazar complete samples", we consider well defined samples of blazars, covering a large range of properties. Indeed one problem to overcome is that until now the observational approach has been mainly "sub–class oriented", focusing on either BL Lacs or FSRQ/HPQ/OVVs separately.
We considered three samples of blazars:

- the "1 Jy" sample of BL Lacs, radio–selected, 34 sources (Stickel et al. 1991);
- the *Einstein* Slew survey (quasi)–complete sample, X–ray selected, 48 sources (Perlman et al. 1996a);
- the FSRQ complete sample drawn by Padovani and Urry (1992) from the Wall and Peacock (1985) catalogue of radio–sources with $F_{2.7\mathrm{GHz}} > 2$ Jy, 50 sources.

2 The SEDs

• **Radio to X–rays:** average spectral energy distributions from the radio to the X–ray band have been constructed. A large fraction of the 132 sources have been observed with the *ROSAT* PSPC allowing to derive "uniformly" X–ray fluxes and in many cases spectral shapes in the 0.1 – 2.4 keV range (Comastri et al. 1997, Lamer et al. 1996, Perlman et al. 1996b, Sambruna et al. 1996a, Sambruna 1997). Fluxes at radio, mm (230 GHz), and optical frequencies were taken from the literature.

The average SEDs presented here are obtained dividing sources in radio (5 GHz) luminosity bins. The true goal would be to divide sources according to their bolometric luminosity (in most cases substantially corresponding to the γ–ray one). On the basis of the empirical relationship that seems to hold between γ–ray and radio (*e.g.* Mattox 1997) luminosity as a first and simpler approach we therefore use the radio power as a good indicator of the total intrinsic luminosity.

Within each luminosity bin, averages were performed over the logarithms of the K–corrected fluxes at each frequency. The average fluxes were then transformed to average luminosities using the average logarithmic distance of the class.

• **γ–ray spectra:** among the three samples only a fraction of blazars were detected in γ–rays, namely 9/34 in "1 Jy" sample, 8/48 in Slew sample, 19/50 in FSRQ sample. Many other blazars ($\sim$ 25) have been detected by EGRET, but do not fall in any well defined sample, apart from the γ–ray one.

To take advantage of the whole body of information regarding the γ–ray properties of blazars, we associated γ–ray properties to our average SEDs following an indirect procedure. We associated to each averaged SED the ($\langle \mathrm{L}_\gamma \rangle$, $\langle \alpha_\gamma \rangle$) of blazars taken from the whole EGRET sample, falling in the corresponding $\mathrm{L}_{5\mathrm{GHz}}$ bin, disregarding their belonging to our complete list. The basic assumption is the uniformity of the spectral properties (for a discussion on this see Impey 1996).

3 Results

As a first check we compared the distributions of various broad band spectral indices (*e.g.* radio–to–X–ray) and luminosities. It is striking that there is no apparent difference in any of the considered quantities between the distributions of γ–ray detected sources and the rest of sample, apart maybe for the Slew sample where there seems to be a tendency for γ–ray detected sources to have larger α_{RX} and $\mathrm{L}_{5\mathrm{GHz}}$. This fact can be due to two different and plausible reasons, that in any case can not be disentangled: i) more luminous sources are more likely to be detected, ii) sources with smaller α_{RX} would have the peak of their Compton component beyond the EGRET band and so they are not easily detectable.

In addition to the average SEDs for each of the three samples (for a thorough discussion see Fossati et al. 1997b), we considered a *total blazars sample*, resulting from their sum. We similarly constructed average SEDs from it, in $\mathrm{L}_{5\mathrm{GHz}}$ bins, independently on the classification originally attached to each source. The result is shown in Fig. 1. Some trends (see also Sambruna et al. 1996b) are evident:

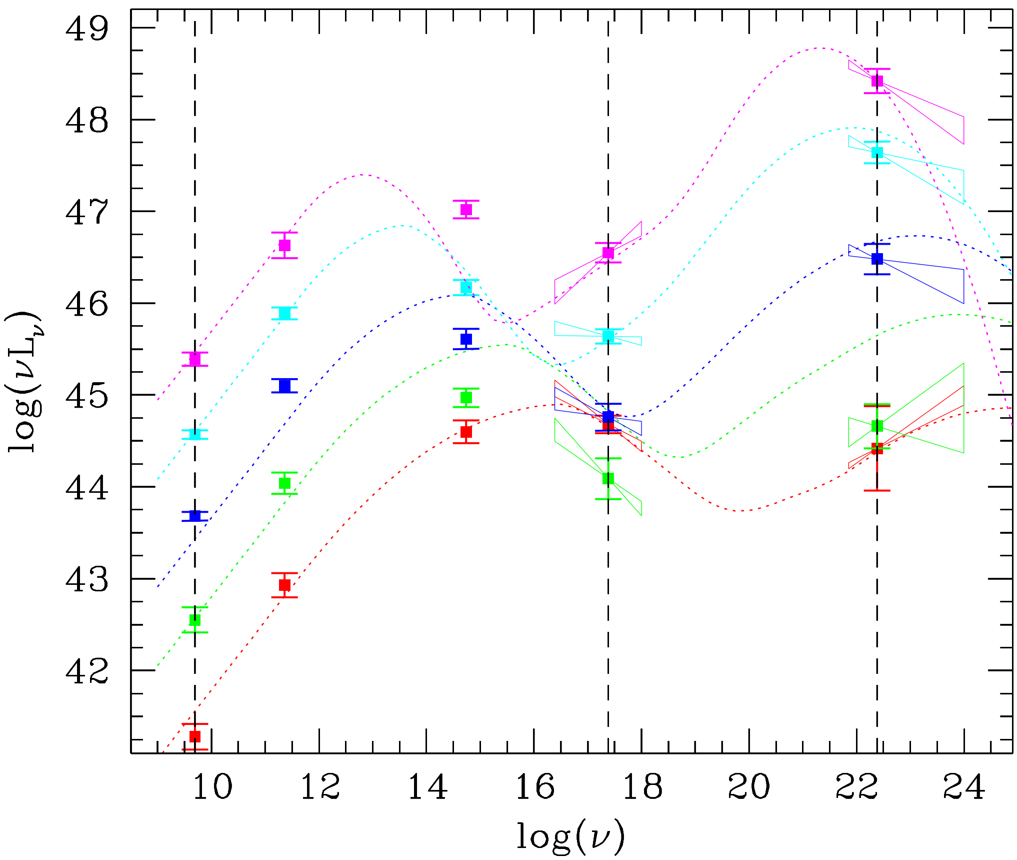

Fig. 3. "total" blazars sample average SEDs with analytic SEDs superimposed.

- the *X–ray spectrum* becomes harder while the *γ–ray spectrum* softens with increasing luminosity (see also Comastri et al. 1997).
- *two peaks* are present in all the SEDs. The first peak moves from $\sim 10^{16} - 10^{17}$ Hz for less luminous sources, to $\sim 10^{13} - 10^{14}$ Hz for the most luminous ones. The location of the second peak can be inferred from the shape of the γ–ray spectrum (γ–ray spectrum steep/medium/flat $\rightarrow$ peak below/within/above the EGRET energy range).
- for a given SED *the frequencies of the two peaks are correlated.*
- the *strength of the γ–ray peak* with respect to the lower frequency one seems to increase with increasing L_{5GHz}

These trends are also present in each of the samples, and strengthened when the total blazar sample is considered, suggesting that we have to do with a *continuous spectral sequence* within the blazar family, rather than with separate spectral classes.

In Fig. 1 we superimposed to real data a set of (dotted) lines, whose main goal is to guide the eye. However we note that the radio–X–ray part is the analytic parameterization proposed by Fossati et al. (1997a), based on the hypothesis that the peak frequency of the first spectral component is inversely related to its luminosity ($\nu_{peak} \propto L^{-1.5}$ in this case).

The second spectral component has been derived assuming that (a) the ratio of the frequencies of the high and low energy peaks is constant ($\nu_H/\nu_L \simeq 5\times10^8$), (b) the high energy peak and radio intensities have a fixed ratio. Given the extreme simplicity of these assumptions, it is remarkable that the phenomenological model fits reasonably well the average SEDs.

4 Conclusions

The main conclusion is that *despite/because of* clear systematic differences between the continua of different blazar sub–classes, a unitary approach is possible.

The physical reason(s) underlying the systematic trends in the SEDs of blazars illustrated here are at present unknown. Ideas under discussion involve the effect of radiative losses on the particle distribution, which could lead to a break at a critical energy $\gamma_{e,break}$. In this case in fact, $\gamma_{e,break}$ would inversely depend on the compactness in seed photons for inverse Compton losses, i.e. $\gamma_{e,break} \propto U_{rad}^{-1}$) (Comastri et al. 1997, Fossati et al. 1997a, Ghisellini et al. 1997).

Systematic determinations of the physical parameters for a number of objects with different values of $\nu_{peak,1,2}$ can therefore give important clues on the relationship between BL Lac objects and FSRQs and on the physical processes governing the radiative properties of relativistic jets (Ghisellini et al. 1997).

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